

# Analysis of the Massive Eclipsing Binary V1441 Aql

Ö. Çakırlı<sup>a,\*</sup>, C. Ibanoglu<sup>a</sup>, E. Sipahi<sup>a</sup>, A. Frasca<sup>b</sup>, G. Catanzaro<sup>b</sup>

<sup>a</sup>*Ege University, Science Faculty, Astronomy and Space Sciences Dept., 35100 Bornova, İzmir, Turkey*

<sup>b</sup>*Osservatorio Astrofisico di Catania, Via S. Sofia 78, 95123 Catania, Italy*

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## Abstract

We present new spectroscopic observations of the early type, double-lined eclipsing binary V1441 Aql. The radial velocities and the available photometric data obtained by *ASAS* is analysed for deriving the parameters of the components. The components of V1441 Aql are shown to be a B3 IV primary with a mass  $M_p=8.02\pm0.51 M_\odot$  and radius  $R_p=7.33\pm0.19 R_\odot$  and a B9 III secondary with a mass  $M_s=1.92\pm0.14 M_\odot$  and radius  $R_s=4.22\pm0.11 R_\odot$ . Our analyses show that V1441 Aql is a double-contact system with rapidly rotating components. Based on the position of the components plotted on the theoretical Hertzsprung-Russell diagram, we estimate that the ages of V1441 Aql is about 30 Myr, neglecting the effects of mass exchange between the components. Using the UBVJHK magnitudes and interstellar absorption we estimated the mean distance to the system V1441 Aql as  $550\pm25$  pc.

**Keywords:** stars: binaries: eclipsing – stars: fundamental parameters – stars: binaries: spectroscopic – stars:V1441 Aql

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\*Corresponding author. Tel.: +902323111740; Fax: +902323731403  
E-mail address: omur.cakirli@gmail.com

## 1. Introduction

High-mass stars are much less frequent than intermediate- or low-mass stars due to both the star formation process, which gives rise to an initial mass function declining with the mass (e.g. Salpeter, 1955; Kroupa, 2001), and to their shorter evolutionary times. However, high-mass stars are very important because they can affect their surroundings with their winds, their strong radiation fields, and their catastrophic death as supernovae, chemically enriching their environment and triggering star formation. They usually form within the dense cores of stellar clusters and/or associations where dynamical interactions play an important role. It is widely believed that massive stars may be the product of collisions between two or more intermediate-mass stars. This idea is supported by the fact that a large fraction of massive stars harbour close companions, as failed mergers. It has been recently estimated that at least 50 % of massive stars are member of binary or multiple star system (Sana et al., 2012). This lucky occurrence allows to directly measure the masses by means of their radial velocity (RV) curves. In many cases, spectral lines of both components are visible (SB2 systems), allowing to derive the orbital parameters like the period,  $P_{\text{orb}}$ , the projected semi-major axes,  $a_{1,2} \sin i$ , and the masses,  $M_{1,2} \sin^3 i$ , apart from the factor  $\sin^3 i$ . If our line-of-sight is close to the orbital plane and fractional radii of the components are not too small the stars display mutually eclipses. The orbital inclination and fractional radii of the component stars can be determined by the analysis of photometric light curves. Therefore, eclipsing binaries are unique targets for determining the masses and radii from their combined light curves and radial velocities analyses. Nevertheless, absolute radii were measured

only for a rather small number of early-type B-stars which are members of eclipsing binary systems (Hilditch, 2004; Torres et al., 2010; Ibanoglu et al., 2013a,b). Thus, we started a systematic observing program devoted to the spectroscopic study of close eclipsing binary systems with at least one hot component.

### 1.1. *V1441 Aquilae*

The eclipsing character of V1441 Aquilae (HD 177624; BD+09°3979; HIP 93732; V=6.90, B-V=0.19 mag) was discovered by the *Hipparcos* satellite mission (Perryman et al., 1997), the primary eclipse having an amplitude of 0.09 mag. The depth of the secondary minimum is nearly half of the primary one. V1441 Aql was first recognized as a double-lined spectroscopic binary by Hill & Fisher (1980). They classified it as a B3V star with semi-amplitudes of radial velocities of about 82 and 196 km s<sup>-1</sup>. The first eclipse light curve (LC) was roughly revealed by the *Hipparcos* observations. Kazarovets et al. (1999) designated it as V1441 Aql in the 74TH NAME-LIST OF VARIABLE STARS, and classified it as an EB. In recent years, large-scale photometric surveys such as All Sky Automated Survey (ASAS, Pojmanski 2002) have been conducted with the main aim of looking for transiting exoplanets. The valuable by-product of these searches has been the very large number of well sampled eclipsing binary LCs. One of the eclipsing binaries observed at the Las Campanas Observatory as part of the ASAS was V1441 Aql. Although the phase coverage is very good the photometric accuracy of the observations is only around 0.05 mag.

The orbital period of V1441 Aql was determined from the spectroscopic observations as 2.374148 days by Hill & Fisher (1980). The first photometric

observations of the system were made by the *Hipparcos* mission and an orbital period of about 2.374 days was estimated (Lefèvre et al., 2009). The *ASAS* photometry permits a redetermination of the orbital period of the system. A periodogram analysis performed with PERIOD04 (Lenz & Breger, 2005), which was applied to all the data obtained by *ASAS*. We derive the following ephemeris

$$MinI(HJD) = 2\,455\,100.4153(32) + 2^d.3741896(16) \times E \quad (1)$$

where the standard deviations in the last significant digits are given in parentheses.

## 2. Observation

Optical spectroscopic observations of V1441 Aql was obtained at the TÜBİTAK National Observatory using the Turkish Faint Object Spectrograph Camera (TFOSC)<sup>1</sup> attached to the 1.5 m telescope. The observations were made from July 22, 2012 to August 3, 2013, under good seeing conditions. Further details on the telescope and the spectrograph can be found at <http://www.tug.tubitak.gov.tr>. The wavelength coverage of each spectrum was 4000-9000 Å in 11 orders, with a resolving power of  $\lambda/\Delta\lambda \sim 7\,000$  at 6500 Å. The average signal-to-noise ratio (S/N) was  $\sim 120$ . We also obtained high S/N spectra of early type standard stars 1 Cas (B0.5 IV), HR 153 (B2 IV),  $\tau$  Her (B5 IV), 21 Peg (B9.5 V) and  $\alpha$  Lyr (A0 V) which were used as templates in derivation of the radial velocities.

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<sup>1</sup><http://http://tug.tubitak.gov.tr/tr/teleskoplar/tfosc>

The echelle spectra were extracted from the raw images following standard reduction steps involving electronic bias subtraction, flat field division, cosmic rays removal, optimal extraction of the echelle orders, and wavelength calibration thanks to the emission lines of a Th-Ar lamp. The reduction was performed using tasks of the IRAF package<sup>2</sup>

### 3. Radial velocities and atmospheric parameters

The time-resolved spectroscopic dataset consists of 17 observations for V1441 Aql. We have measured radial velocities (RVs) from the spectra, focusing on spectral segments containing the He I  $\lambda 5876$  (order 4) and  $\lambda 6678$  (order 3) lines which are the most prominent un-blended features in our spectra, apart from the Balmer lines. We have employed the standard cross-correlation method for measuring the velocities of the component stars of the systems. The numerical cross-correlation technique (Simkin, 1974; Tonry & Davis, 1979) is a standard approach for measuring RVs from the spectra of close binary systems. Cross-correlation analyses were made using the spectra of  $\tau$  Her and 21 Peg as templates. The principle spectral features showing splitting due to binarity were the He I lines at  $\lambda\lambda 5876$  and  $6678$ . We used also order 9, containing the He I  $\lambda 4471$  line, for a few measurements of the radial velocities. The spectra taken close to the conjunctions, which display no double-lined feature, were disregarded. The Balmer lines were not used in the measurements of radial velocities due to their extremely broad

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<sup>2</sup>IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc. (AURA), under cooperative agreement with the National Science Foundation.

profiles.

We obtained 17 radial velocities for each component of V1441 Aql. The average radial velocities and their associated standard errors derived from the spectral segments containing He I  $\lambda\lambda 4471$ , 5876, and 6678 lines are presented in Table 1, along with the observation date and orbital phase. The mean error of radial velocities is  $3.6 \text{ km s}^{-1}$  for the primary, and  $8.5 \text{ km s}^{-1}$  for the secondary star of V1441 Aql. The RVs are plotted against the orbital phase in Fig. 1, where the filled squares represent the primaries and the empty squares the secondaries, respectively. Examination of the *ASAS* light curve show no evidence for any eccentricity in the orbits of both systems. Therefore, we have assumed circular orbits and analysed the RVs using the *RVSIM* software programme (Kane et al., 2007). Final orbital parameters are presented in Table 2.

Intermediate-resolution optical spectroscopy permits us to derive most of the fundamental stellar parameters, such as the projected rotational velocity ( $v \sin i$ ), spectral type ( $S_p$ ), luminosity class, effective temperature ( $T_{\text{eff}}$ ), surface gravity ( $\log g$ ), and metallicity ( $[\text{Fe}/\text{H}]$ ).

The width of the cross-correlation function (CCF) is a good tool for the measurement of projected rotational velocity ( $v \sin i$ ) of a star. We use a method developed by Penny (1996) to estimate the  $v \sin i$  of each star composing the investigated SB2 systems from its CCF peak by a proper calibration based on a spectrum of a narrow-lined star with a similar spectral type. Per each system, the rotational velocities of the components were obtained by measuring the FWHM of the CCF peak related to each component in five high-S/N spectra acquired near the quadratures, where the spectral

lines have the largest Doppler-shift. The CCFs were used for the determination of  $v \sin i$  through a calibration of the full-width at half maximum (FWHM) of the CCF peak as a function of the  $v \sin i$  of artificially broadened spectra of slowly rotating standard star (21 Peg,  $v \sin i \simeq 14 \text{ km s}^{-1}$ , e.g., Royer et al. 2002) acquired with the same setup and in the same observing night as the targets systems. The limb darkening coefficient was fixed at the theoretically predicted values, 0.42 for both systems (van Hamme, 1993). We calibrated the relationship between the CCF Gaussian width and  $v \sin i$  using the Conti & Ebbets (1977) data sample. This analysis yielded projected rotational velocities for the components of V1441 Aql as  $v_p \sin i = 196 \text{ km s}^{-1}$ , and  $v_s \sin i = 101 \text{ km s}^{-1}$ . The mean deviations were 4 and 7  $\text{km s}^{-1}$ , for the primary and secondary, respectively, between the measured velocities for different lines.

We also performed a spectral classification for the components of the systems using COMPO2, an IDL code for the analysis of high-resolution spectra of SB2 systems written by one of us (see, e.g., Frasca et al., 2006) and adapted to the TFOSC spectra. This code searches for the best combination of two reference spectra able to reproduce the observed spectrum of the system. We give, as input parameters, the radial velocities and projected rotational velocities  $v \sin i$  of the two components of each system, which were already derived. The code then finds, for the selected spectral region, the spectral types and fractional flux contributions that better reproduce the observed spectrum, i.e. which minimize the residuals in the collection of difference (observed – composite) spectra. For this task we used reference spectra taken from the Valdes et al. (2004) *Indo* –

Table 1: Heliocentric radial velocities of V1441 Aql. The columns give the heliocentric Julian date, orbital phase and the radial velocities of the two components with the corresponding standard deviations.

HJD 2400000+	Phase	V1441 Aql			
		$V_P$	$\sigma$	$V_S$	$\sigma$
56131.3242	0.2137	−54	3	167	8
56132.2925	0.6216	38	3	−157	8
56133.4035	0.0895	−33	3	89	7
56134.4926	0.5483	11	2	−54	8
56135.4443	0.9491	11	2	−66	5
56136.2708	0.2972	−51	5	166	7
56137.2913	0.7270	44	5	−189	9
56147.3444	0.9614	9	3	−71	7
56167.4232	0.4185	−31	2	77	7
56506.4817	0.2287	−61	3	167	4
56506.4993	0.2361	−55	3	178	5
56507.2803	0.5651	12	4	−60	9
56507.2957	0.5716	17	4	−67	11
56507.3107	0.5779	21	4	−91	8
56507.4161	0.6222	27	4	−141	9
56507.4338	0.6297	37	6	−137	8
56507.4494	0.6363	33	5	−133	8



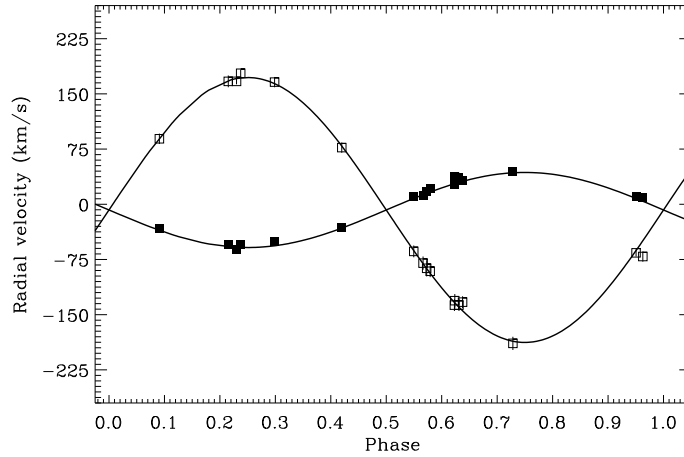


Figure 1: Radial velocities for the components of V1441 Aql. Filled squares correspond to the radial velocities for the primary and the empty squares for the secondary star. Error bars are shown by vertical line segments, which are smaller than symbol sizes. The solid lines are the computed radial velocity curves for the component stars.

Table 2: Results of the radial velocity analysis for V1441 Aql.

Parameter	V1441 Aql	
	Primary	Secondary
$k$ (km s $^{-1}$ )	$44 \pm 2$	$184 \pm 4$
$V_\gamma$ (km s $^{-1}$ )	$-3.5 \pm 0.2$	
Average O-C (km s $^{-1}$ )	3.6	7.5
$a \sin i$ ( $R_\odot$ )	$2.064 \pm 0.002$	$8.631 \pm 0.006$
$M \sin^3 i$ ( $M_\odot$ )	$2.353 \pm 0.140$	$0.563 \pm 0.041$

*U.S. Library of Coude Feed Stellar Spectra* (with a resolution of  $\approx 1\text{\AA}$ ) that are representative of stars with spectral types from late-O type to early-A, and luminosity classes V, IV, and III. The atmospheric parameters of these reference stars were recently revised by Wu et al. (2011).

We selected 198 reference spectra spanning the ranges of expected atmospheric parameters, which means that we have searched for the best combination of spectra among 39 204 possibilities per each spectrum. The observed spectra of V1441 Aql in the  $\lambda\lambda 6525\text{--}6720$  spectral region were best represented by the combination of HD 179761 (B8 II-III) and HD 182568 (B3 IV). However, we have adopted, for each component, the spectral type and luminosity class with the highest score in the collection of the best combinations of templates, where the score takes into account the goodness of the fit expressed by the minimum of the residuals. We have thus derived a spectral type of B3 subgiant for the primary and B9 giant for the secondary star of V1441 Aql, with an uncertainty of about 1 spectral subclass. The effective temperature and surface gravity of the two components of each system are obtained as the weighted average of the values of the best spectra at phases near to the quadratures combinations of templates adopting a weight  $w_i = 1/\sigma_i^2$ , where  $\sigma_i$  is the average of residuals for the  $i$ -th combination. The standard error of the weighted mean was adopted for the atmospheric parameters. Both stars appear to have a solar metallicity, within the errors. The atmospheric parameters obtained by the code and their standard errors are reported in Table 3. The observed spectra of V1441 Aql at phases near to the quadratures are shown in Fig. 2 together with the combination of two reference spectra which gives the best match.

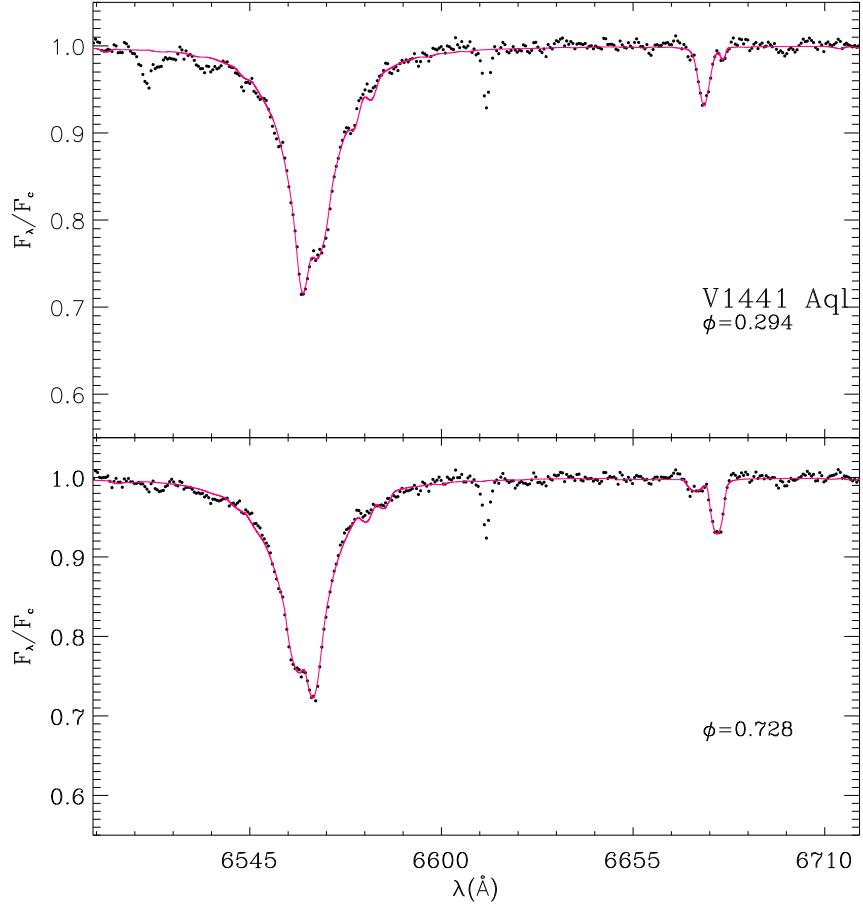


Figure 2: Two spectra of V1441 Aql near opposing quadrature phases, at phases 0.294 and 0.728. The wavelength limits are 6525-6715  $\text{\AA}$ , which include the H $\alpha$  and He I  $\lambda$ 6678 lines. The deeper lines in each spectra refer to the primary star. Vertical axis is the normalized flux.

Table 3: Spectral types, effective temperatures, surface gravities, and rotational velocities of the components estimated from the spectra of V1441 Aql.

Parameter	V1441 Aql	
	Primary	Secondary
Spectral type	B(3 $\pm$ 0.5) IV	B(9 $\pm$ 0.5) III
$T_{\text{eff}}$ (K)	18 760 $\pm$ 950	11 670 $\pm$ 650
$\log g$ ( <i>cgs</i> )	3.77 $\pm$ 0.05	3.95 $\pm$ 0.17
$v \sin i$ (km s $^{-1}$ )	196 $\pm$ 4	101 $\pm$ 7

#### 4. Analyses of the light curve

We extracted the V-band light curve for V1441 Aql (ASAS190509+0938.5) from the All Sky Automated Survey database (Pojmanski, 2002). The light curve composed of 375 photometric points, has a very good phase coverage and displays two equally spaced minima whose depths are about 0.09 and 0.04 mag. The observed light curve is reminiscent of an ellipsoidal variable with tidally distorted stars. V1441 Aql was also observed by the *Hipparcos* satellite (Perryman et al., 1997). 69 Hp magnitudes were obtained for V1441 Aql. The light curve is similar to that obtained by *ASAS* but its shape is poorly defined due to small number of measurements. Malkov et al. (2006) estimate an Hp magnitude of 6.91 at the light maximum and a primary minimum with a depth of 0.09 mag in the *Hipparcos* light curve. The light curve obtained by the *ASAS* is shown in Fig. 3, where the vertical axis is the normalized flux.

The effective temperature of the primary star and the mass-ratio of the

system are key parameters needed for the analysis of the light curve. The effective temperatures of both components have already been determined from the spectra as  $18\,760 \pm 950$  K and  $11\,670 \pm 650$  K as well as a mass-ratio of  $0.239 \pm 0.009$  was derived from the radial velocity curve solution. Another approach to estimating the temperature of the primary star is to use the observed colours of the system. The apparent visual magnitude and colour indices were given as mean of nine measures by Moreno (1971) as  $V = 6^m.90$ ,  $(U - B) = -0^m.36$ ,  $(B - V) = 0^m.19$  and  $(V - R) = 0^m.23$  with an uncertainty of  $\pm 0.01$  mag. The quantity  $Q = (U - B) - 0.72(B - V)$  of the Johnson's UBV photometric system is independent of interstellar extinction. We compute the reddening-free index as  $Q = -0.497$  for the system, which corresponds to a B4 star (Hovhannessian, 2004), consistent with the spectral classification from the spectra. The effective temperature for the primary star, derived from the spectra, corresponds to an intrinsic colour of  $(B - V) = -0^m.22$ . A preliminary analysis of the light curve yields a light ratio of  $l_s/l_p = 0.15$  for the V-passband. Using the intrinsic colour of the primary star, the light ratio and observed colour of  $0^m.19$  we compute an intrinsic composite colour for the system as  $(B - V) = -0^m.21$ . Then we estimate the reddening for the system as  $E_{(B-V)} = 0^m.40$ .

Since the *Hipparcos* data contain only 69  $H_p$  points with uncertainties larger than the *ASAS* ones, we did not attempt to analyze them for determination of the orbital parameters. We started to analyze the *ASAS* light curve using the Wilson-Devinney code (hereafter WD; e.g., Wilson & Devinney, 1971; Wilson, 1979, 2006) as implemented in the software PHOEBE (Prša & Zwitter, 2005). The WD code is widely used for determination of the orbital pa-

Table 4: Final solution parameters for the double-contact model of V1441 Aql.

Parameters	V1441 Aql
$i^\circ$	$41.65 \pm 0.58$
$T_{\text{eff}_1}$ (K)	18 760[Fix]
$T_{\text{eff}_2}$ (K)	$11\,650 \pm 300$
$\Omega_1$	$2.327 \pm 0.030$
$\Omega_2$	$2.327 \pm 0.030$
$r_1$	$0.4557 \pm 0.0065$
$r_2$	$0.2620 \pm 0.0033$
$\frac{L_1}{(L_1+L_2)}$	$0.8721 \pm 0.0035$
$\sum(O - C)^2$	0.0370
$N$	375
$\sigma$	0.0100

rameters of the eclipsing binaries. To run the code we need some initial elements. The logarithmic limb-darkening coefficients were interpolated in effective temperature and surface gravity from the coefficients tabulated by van Hamme (1993). The initial limb-darkening coefficients were taken as  $x_1=0.45$ ,  $y_1=0.24$ ,  $x_2=0.59$ ,  $y_2=0.29$  for the hotter and cooler star, respectively. They are updated at every iteration. The gravity-brightening coefficients  $g_1=g_2=1.0$  and albedos  $A_1=A_2=1.0$  were fixed for both components, as appropriate for stars with radiative atmospheres. We started with the *Mode* – 2 option of the WD code, designed for detached binaries, for the analysis of light curves as described by Wilson (2006). The adjustable parameters in the light curve fitting were the orbital inclination  $i$ , the effective temperature of the secondary star  $T_{\text{eff}_2}$ , the monochromatic luminosity of the primary  $L_1$ , and the zero-epoch offset. We could not obtain a good fit of the light curve with a detached configuration. This led us to try with a semi-detached configuration. We thus applied *Mode* – 5 option of the WD

code, in which the secondary star fills its lobe. The convergence was obtained with the primary star overfilling its lobe. Then we tried the *Mode* – 3 (for overcontact systems, the stars are in geometrical contact without being in thermal contact). This solution resulted in that both stars are well inside their lobes. Then we applied *Mode* – 4 (primary star fills its lobe) but we arrived at a result that the secondary star is overfilling its lobe.

Finally, the solution with the *Mode* – 6 option (for double contact systems, DCSs) resulted in acceptable parameters. Wilson (1979) defined DCSs as a binaries in which both stars fill their Roche lobes and at least one rotates faster than synchronously, so that the components do not touch, even at one point. The fits of the computed light curves obtained with *Mode* – 6 to the observations are satisfactory with the smallest sum of residuals squared. The out-of-eclipse part of the observed light curve is now better reproduced. We have already measured the projected rotational velocities from the spectral lines for the components of V1441 Aql. Preliminary analysis using the *Mode* – 6 of WD code yielded orbital parameters for the component stars. We have computed projected rotational velocities of the components. A comparison of the observed rotational velocities with those computed velocities shows that the stars rotate faster than the synchronous values. Therefore we repeated our analysis taking  $F_1=1.8$  and  $F_2=1.6$ .

The parameters of our final solutions are listed in Table 4. The orbital inclination of the system, effective temperatures, fractional mean radii (equivalent volume) of the components and fractional luminosity of the primary star in the V band were given in this table. The uncertainties assigned to the adjusted parameters are the internal errors provided directly by the code.

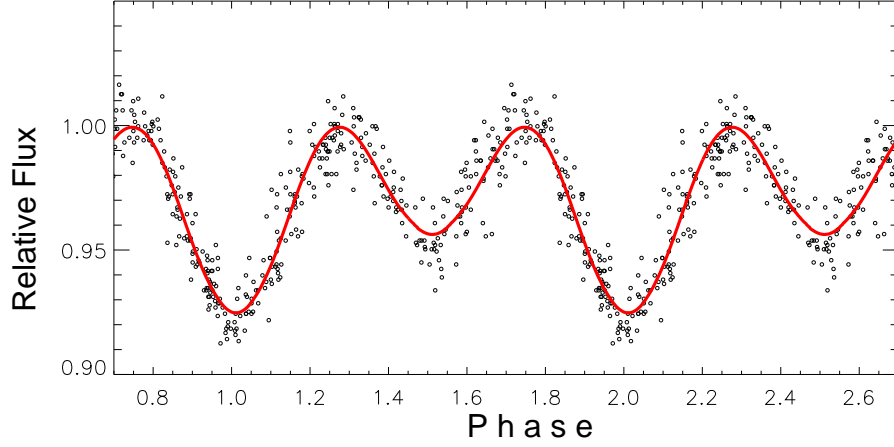


Figure 3: Observed (dots) and computed ASAS V-band light curve of V1441 Aql. The vertical axis is the normalized flux and the abscissa is the orbital phase.

The squared sum of residuals,  $\sum(O-C)^2$ , the number of data points,  $N$ , and the standard deviation,  $\sigma$ , of the observed light curve are quoted in the last three lines of Table 4, respectively. The computed light curve is overplotted to the observations in Fig. 3. This solution indicates for V1441 Aql a grazing eclipse lasting about half an hour.

## 5. Results and discussion

Based on the results of radial velocities and light curves analyses we have calculated the physical properties of the V1441 Aql. For this purpose, we used the *JKTABSDIM* code developed by Southworth et al. (2005). This code is now widely used for derivation of the absolute parameters of the eclipsing binary stars' components. It calculates complete error budgets using a perturbation algorithm. The fundamental stellar parameters for the



components such as masses, radii, luminosities and their standard deviations have been derived using this code. The astrophysical parameters of the components, and other properties for the components of V1441 Aql are presented in Table 5.

The separation between the components was found to be  $16.09 \pm 0.34 R_{\odot}$  for V1441 Aql. The masses were measured to precision of about 6–7 % for the components. On the other hand the radii of the components have been derived with a precision of better than 5 %. The accuracy of any parameter of an eclipsing binary system depends mainly on the coverage of the both spectroscopic and photometric observations and their precision. In addition, the light curve solutions are more accurate for totally eclipsing systems. The light curve of V1441 Aql shows instead a very shallow grazing eclipse. Despite these drawbacks, the physical parameters of the components of system could be determined with sufficient precision. We note that the effective temperatures of the secondary stars derived from the spectra are in good agreement with those obtained from the light curve analyses.

The luminosities and absolute bolometric magnitudes are calculated directly from the radii and effective temperatures of the components. The effective temperature of 5 777 K and the absolute bolometric magnitude of 4.74 mag were adopted for the Sun (e.g., Drilling & Landolt , 2000). The bolometric corrections were interpolated from the tables of Flower (1996). The V-band magnitudes of the systems at out-of-eclipse phases are taken as 6.90 and 7.32 for V1441 Aql. We have calculated the absolute visual magnitudes for the components using the fractional luminosities and bolometric corrections given in Table 4 and 5. Combining these values with the interstel-

lar absorption of 1.27 mag for V1441 Aql and we have estimated the distances to the systems as  $550 \pm 25$ .

In the  $\log T_{\text{eff}} - \log L/L_{\odot}$  (left panel) and  $\log T_{\text{eff}} - \log g$  planes (right panel) we have plotted the positions of the components (Fig. 4), with  $1-\sigma$  error bars. The filled and empty squares refer to the components of V1441 Aql. The evolutionary tracks and isochrones for the non-rotating single stars with solar composition are taken from Ekström et al. (2012).

The most striking result from analyses of the radial velocities and light curve is the double-contact configuration of V1441 Aql. Double-contact systems (DCSs) were described in detail by Wilson (1979). He showed that in the double-contact systems the massive stars do not rotate synchronously. Wilson et al. (1985) estimated for the first time the rotation rate of a star in an eclipsing binary using photometric observations. They showed that the primary star of the double-contact system RZ Sct rotates about at 6.7 times the synchronous value. Very recently, Terrell & Nelson (2014) discussed the double-contact nature of the eclipsing binary system TT Her. They have already shown that the observed radial velocities and light curves could only be represented with a non-synchronous rotation of the primary star. Their analyses resulted in that the more massive star rotates at 1.25 times the synchronous value. Our measured projected rotational velocities for V1441 Aql show that both components rotate faster than the synchronous values, amounting to about  $1.7v_{\text{syn}} \sin i$ .

The comparison with the evolution of single stars, shown in Fig. 4, indicates that the age of V1441 Aql is longer than 30 Myr. Both stars have evolved away from the main sequence, i.e. exhausted the hydrogen in their

cores. The primary star is probably in the shell hydrogen burning phase. While the more massive star appears to be crossing the Hertzsprung gap in the HR diagram, the less massive star is close to the base of giant branch. In addition, the secondary component is seen as an over-luminous and hotter star with respect to its mass. This may indicate that the secondary star lost the outer envelope during the evolution in past. At present, it has a larger radius and therefore has a higher luminosity, similar to the donors in the semi-detached Algol-type binaries.

We calculated the synchronization time for V1441 Aql as about 2 Myr using the hydrodynamic damping formalism of Tassoul & Tassoul (1997). The Tassouls' synchronization time is about 15 times shorter than the estimated age of the binary. Both observational (Glazunova et al., 2008) and theoretical (Dervişoğlu et al., 2010) studies showed that the mass-gainers of the semi-detached close binaries rotate faster than synchronous. There is a consensus that the most plausible reason for this asynchronous rotation of the primaries is the high values of the mass transfer rate. Dervişoğlu et al. (2010) recently showed a relation between mass transfer rate and asynchronous rotation velocity of the gainers in the Algol-type systems. The double-contact nature of V1441 Aql with asynchronous components indicates that it has passed through rapid phase of mass transfer.

## 6. Summary

V1441 Aql is close eclipsing binaries containing high-mass stars. We carried out spectroscopic observations of system. The atmospheric parameters of the components in the eclipsing pairs have been determined from their

Table 5: Absolute parameters, magnitudes and colours  
for the components of V1441 Aql.

Parameter	Units	V1441 Aql	
		Primary	Secondary
Mass	$M_{\odot}$	$8.02 \pm 0.51$	$1.92 \pm 0.14$
Radius	$R_{\odot}$	$7.33 \pm 0.19$	$4.22 \pm 0.11$
$T_{\text{eff}}$	K	$18\,760 \pm 950$	$11\,650 \pm 300$
$\log(L/L_{\odot})$		$3.779 \pm 0.091$	$2.471 \pm 0.047$
$\log g$	<i>cgs</i>	$3.611 \pm 0.016$	$3.471 \pm 0.023$
<i>Sp.Type</i>		B3IV	B9III
$M_{\text{bol}}$	mag	$-4.70 \pm 0.23$	$-1.43 \pm 0.12$
$BC$	mag	$-1.75$	$-0.61$
$M_V$	mag	$-2.95 \pm 0.11$	$-0.82 \pm 0.07$
$v \sin i_{\text{cal}}$	$\text{km s}^{-1}$	$104 \pm 3$	$60 \pm 2$
$v \sin i_{\text{obs}}$	$\text{km s}^{-1}$	$196 \pm 4$	$101 \pm 7$
$d$	pc	$560 \pm 32$	$548 \pm 22$

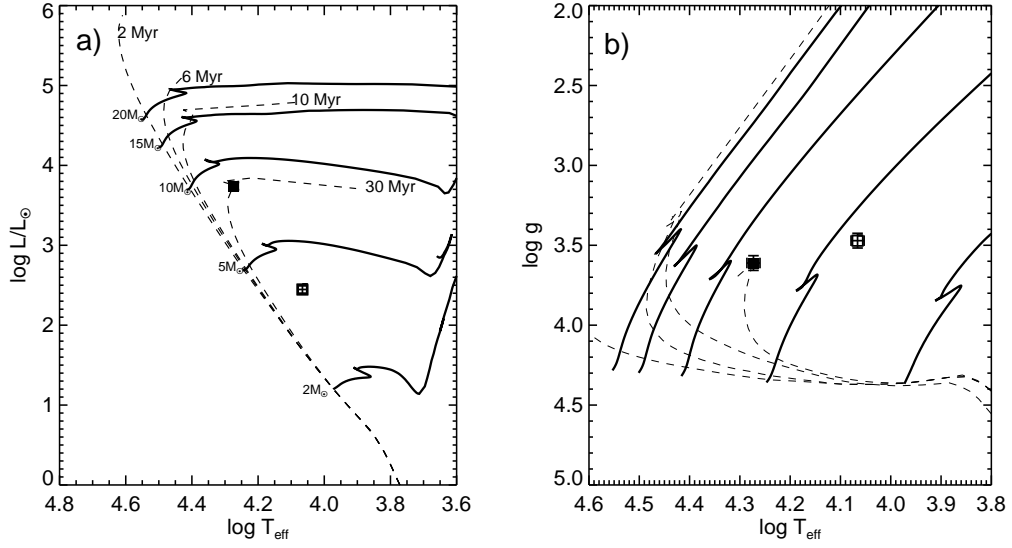


Figure 4: Positions of the components of the systems in the luminosity-effective temperature and gravity effective temperature planes are plotted. The filled and empty squares refer the components of V1441 Aql. The solid lines show evolutionary tracks for single stars with masses of 20, 15, 10, 5 and 2 solar masses for solar composition taken from Ekström et al. (2012). The stars of V1441 Aql are departed from the main-sequence, locating at the Hertzsprung gap and close to the base of giant branch with an age of about 30 Myr.

spectra. The spectra were analyzed using cross-correlation for measuring the radial velocities of both components and with an ad-hoc code for deriving their atmospheric parameters. Moreover, the *ASAS* and *HIPPARCOS* light curves were modeled using the WD code. The physical parameters for the system is measured to accuracies of 6-7% in mass, and 5% in radius. V1441 Aql seems to a double-contact system with asynchronously-rotating components. The distances to the systems V1441 Aql is estimated as  $550 \pm 25$  pc. A comparison of physical parameters of the components with the theoretical models of single stellar evolution models has been made. An age of about 30 Myr is estimated for V1441 Aql.

## Acknowledgments

We thank to TÜBİTAK National Observatory (TUG) for a partial support in using RTT150 telescope with project number 11BRTT150-198. We thank to EBİLTEM Ege University Research Center for a partial support with project number 2013/BIL/018. We also thank to the staff of the Bakırlitepe observing station for their warm hospitality. This study is supported by Turkish Scientific and Technology Council under project number 112T263. This research was also partly supported by the Scientific Research Projects Coordination Unit of Istanbul University. Project number 3685. We thank Canakkale Onsekiz Mart University Astrophysics Research Center and Ulupinar Observatory together with Istanbul University Observatory Research and Application Center for their support and allowing use of IST60 telescope. This work was partially supported by the Italian *Ministero dell'Istruzione, Università e Ricerca* (MIUR). The following internet-based resources were used

in research for this paper: the NASA Astrophysics Data System; the SIMBAD database operated at CDS, Strasbourg, France; and the arXiv scientific paper preprint service operated by Cornell University.

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